parture was in Kansas, and the high-level cell was almost directly overhead.

Maj. E. H. Bowie has drawn my attention to an article by George Reeder which appeared in the MONTHLY WEATHER REVIEW of October 1919, entitled "The Relationship between Cirrus Movements from Easterly Points, and the Occurrence of Severe Droughts," in which the author showed that during severe droughts in summer in Missouri, and preceding them, "the cirriform clouds show a persistent though very sluggish movement from easterly points." Lacking free-air data, Mr. Reeder endeavored to account for this abnormal cloud movement by a study of surface pressures. It is quite likely that had he possessed the information which we now have regarding air circulation at high levels he would have attributed the phenomenon to other causes, for the easterly winds over Missouri could occur only when the high-level anticycline was far north and east of its normal position. Figures 8 and 9, just considered, may be taken as an example of an air structure probably approximating situations of the kind he described. It will be noted that in each case there was a northwest resultant wind over the upper Mississippi Valley, countered further south by a southeast resultant wind over Oklahoma. Note, too, the close agreement between resultant winds and isotherms, and how the high-level circulation has apparently maintained an air mass of abnormal warmth far eastward over the Mississippi Basin, and hence an atmospheric structure hostile to convection.

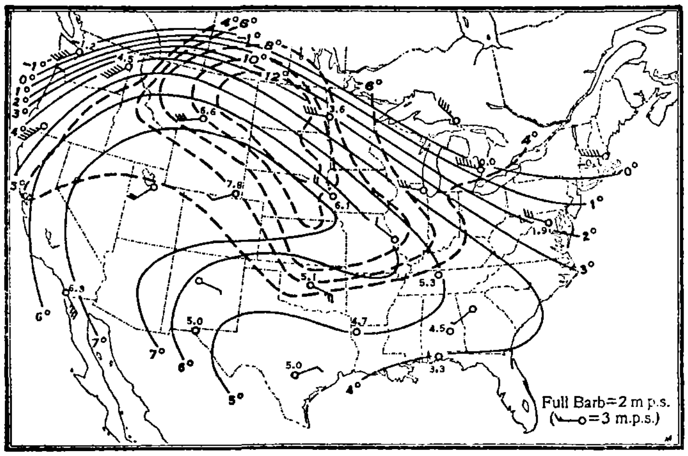


FIGURE 8.—July 1936. A month of unusual heat and drought in the Middle West Solid lines indicate isotherms at 4,000 m., °C.; broken lines, departures from normal temperature at surface, °F.; resultant winds at 4,000 m.

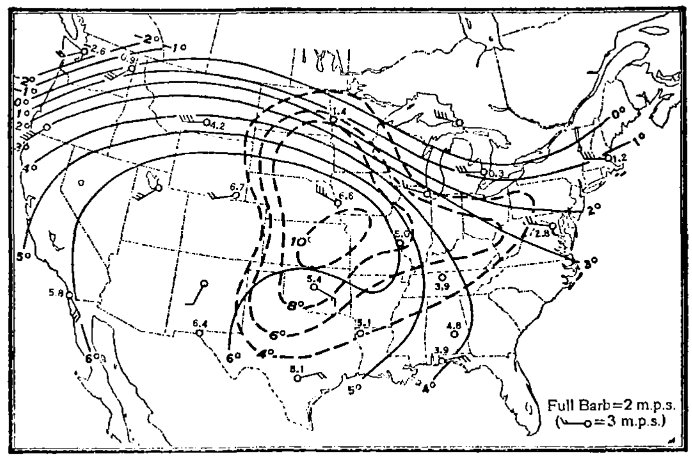


FIGURE 9.—August 1936. A month of unusual heat and drought east of the Rocky Mountains. Solid lines indicate isotherms °C. at 4,000 m.; broken lines, departures from normal temperature at surface °F; resultant winds at 4,000 m.

Special thanks are due Messrs. Little and Samuels of the Aerological Division of the Weather Bureau for help in providing data for some of the charts herewith.

FURTHER STUDIES OF AMERICAN AIR-MASS PROPERTIES

By ALBERT K. SHOWALTER

[Weather Bureau, Washington, June 1939]

These studies originally were undertaken for the purpose of bringing up to date the mean values of the characteristic air-mass properties of North America as first given by Willett (*1*). This seemed desirable in view of the large mass of airplane sounding data obtained since the publication of Willett's paper, which was based principally on kite observations. A preliminary analysis of the new data indicated that some minor changes in Willett's classification of air masses might be necessary. A more thorough study, however, based also on certain synoptic considerations, led to the abandonment of the absolute system of classifications, for reason that will be stated later; and the conclusion was reached that Bergeron's differential classification, which was used by Willett as an alternative system, forms a better basis for air-mass definitions.

The relation between the two classifications can be seen by listing and comparing them as follows:

Absolute classification (adapted from Willett)

Pc—Polar continental air which, after becoming modified, is called Npc (transitional polar continental).

Pp—Polar Pacific, and the modified form Npp.

Pa—Polar Atlantic, which, when modified, becomes Npa.

Ta—Tropical Atlantic, which in the charts and cross sections used for this study, included both the Ta and Tg (tropical Gulf) masses of Willett's classification, since both of the air masses come out of the subtropical anticyclone cell of the Atlantic.

Tp—Tropical Pacific.

Tm—Tropical maritime, a designation used when it is impossible to determine whether the air mass is of Atlantic or Pacific origin or when the two are mixed.

S—Superior, which includes all air masses which appear warm and very dry because, principally, of subsidence and divergence. S includes the type of air mass labeled Tc (tropical continental) in Willett's original publication and Ts (tropical superior) in later treatises by the same author (*2*).

Np—Modified polar, which is air definitely of polar origin but of doubtful continental or maritime origin, or a mixture of continental and maritime polar air. This type of air mass, which was not definitely classified by Willett, forms the predominant polar air mass of summer.

NPM—Modified moist polar; air which has become very moist (high relative humidity, moderately high temperature) by any of several possible means—by a long history over water, by precipitation through it, by evaporation into it from the surface, by mixing with TM air, or perhaps in some cases by cooling, either radiational or dynamic. This classification is not very desirable from a geographical standpoint, but for practical purposes it was used at first in the study. It included the terms NP *becoming* TM; NPPM, NPP *becoming* TP; NPC *becoming* NPA, NPA, NP+TM; and similar terms employed on synoptic charts and cross sections. The NPM designation does not appear in Willett's classification.

Differential classification (*adapted from Bergeron*) (**3**)

This classification implies the existence of two fronts separating three air masses—the Arctic front between Arctic and polar air, and the polar front separating polar from tropical air; the intertropic front does not enter into the scheme of things as far as the United States is concerned. The Arctic front, through southward migrations of the cold air, becomes a polar front, at which stage a new Arctic front usually is created, at least in winter. The minor cold and warm fronts, occluded fronts, etc., of middle latitudes are sections of the polar front; in fact under ordinary conditions the polar front is not a single, continuous front, although frequently it is approximately so.

cAw—Continental Arctic air, warmer than the surface over which it lies (stable in the low layers). This corresponds to the pure Pc air mass at its source.

cAK—Continental Arctic air, colder than the surface over which it is passing (steep lapse rate in the lower layers). This corresponds to pure Pc air that is moving rapidly and undergoing convectional or mechanical convergence around (usually behind) an intense cyclone in high latitudes.

mAK—Maritime Arctic air, colder than the surface over which it is passing (steep lapse rate). This corresponds to a mixture of Pc and PP air masses flowing together rapidly down the Alaskan Pacific coast toward the United States, producing a type of weather somewhat distinct from that produced by the usual PP.

cPw—Continental polar air, warmer than the surface over which it is passing (stable in the lower layers). Corresponds to stable NPC, PP, or NPP modified over the continent, the latter type sometimes classified as NPPC [see Byers (**4**)].

cPK—Continental polar air, colder than the surface over which it is passing (steep lapse rate). Corresponds to NPC, NPPC, and NP that have been heated from below, especially in summer.

mPw—Maritime polar air, warmer than the surface over which it is passing (stable in the lower layers). Corresponds to a return current of NPP over the ocean (NPPM according to Byers) or PP becoming NPP by rapid cooling in the valleys and basins of the Far West in winter. Sometimes also corresponds to a return current of stable NPA, or NPM.

mPK—Maritime polar air, colder than the surface over which it is passing (steep lapse rate). Corresponds to fresh PP and some forms of NPP, PA, and NPM.

mTw—Maritime tropical air, warmer than the surface over which it is passing (stable in the lower layers). Corresponds to certain types of TA, TP, and NPM.

mTK—Maritime tropical air, colder than the surface over which it lies or is passing (steep lapse rate). Corresponds to TA, perhaps occasionally also TP.

Superior air (S) is not of surface origin and is the same in both classifications. Continental tropical air does not appear in North America.

The outstanding characteristics of the various air masses may be outlined as follows:

WINTER SEASON

Continental Arctic Air

As shown by Willet (**1**) and Wexler (**5**) cA air is probably formerly maritime polar air (mPK) which is cooled by surface radiation forming cAw. A study of this air mass by Wexler has shown that there is a very sharp inversion near the surface, and above, a lapse rate approaching the isothermal. The rapid increase with height of potential temperature as shown for cAw air in figure 2 illustrates the exceptional stability of this air mass. Since the effect of surface cooling rarely extends above 3 km. above sea level, the uncooled air above would still be mP and very few observations of cA air are available above that level. Occasionally cA air is mechanically lifted to 4 km. at Cheyenne and in such a case it will be cooled adiabatically and a temperature very low for that height will result. Unstable Arctic air, cAK, sometimes occurs in the Hudson Bay and the Great Lakes regions but insufficient data are available to include cAK air in this study.

The modifying influences affecting cA air are principally the addition of heat and moisture at the surface and a tendency for subsidence aloft. A complete discussion of cA (Pc) air and other air masses is contained in Willett's paper and it is the author's intention to avoid needless repetition of the important modifying influences. The change in designation from cAw to cPw has been more or less arbitrary but usually one or two days elapse before cAw air is considered cPw. A more definite criterion for the change in notation is the formation of a new Arctic front. Eventually the original polar air may become tropical air, so cPw merely marks the transitional stage.

The striking thing in the movement of cAw *becoming* cPw air into the southern United States is that the steepening of the lapse rate which would be expected from the addition of heat from below does not occur in the mean, except in the lowest few hundred meters. Apparently subsidence proceeds so rapidly at all levels above the shallow turbulent-convective layer that the great stability characteristic of cAw air near its source is still preserved and cAw→cPK is rare, except behind deepening cyclones. As the polar air feeds into low latitudes it spreads out to occupy several times its original area and thus the compensating subsidence shown by the various charts and tables is accounted for.

The properties of cPw air, as would be expected, are about midway between the properties of Arctic and Tropical air.

There seems to be considerable moisture added in the lower levels by surface evaporation but because of the extreme stability of cAw and cPw air it does not seem likely that the effects of surface addition of moisture extend to any appreciable elevation. Consider for example, the mean value of 2.2 g./kg. for specific humidity with a potential temperature of 288°A. at 2 km. at Oklahoma City in cPw air. (See fig. 2.) To establish an adiabatic lapse rate to carry such a quantity of moisture up to 2 km. by vertical convection, a potential temperature of 288° A. is required at the surface. Since a surface potential temperature of 288° A. is found only in air of air mass, and employing a pseudo-adiabatic diagram, it is found that the assumed conditions result in a specific humidity of 2.8 g./kg., and an equivalent-potential temperature of 280° A. If vertical convection with constant equivalent-potential temperature obtained to 5 km. above sea level in such an air mass the temperature at 5 km. would be about −43° C. The lowest temperature observed at 5 km. in mAk air was −43.4° C. at Spokane on February 7, 1936. It must be borne in mind that the above are minimum values of the properties of mAk air and most of the outbreaks do not result in such low values. In fact the mean values here summarized are much too high for typical mAk air. The means were obtained from sampling of air originally classified as Pp. They represent observations of mAk, mAk→mPk or mPw, and mPk→mPw. Strictly speaking, for air masses entering the United States, the notation mAk should be reserved for Arctic air masses which move directly southward along the North Pacific coast and have only a short trajectory over the ocean. The notations mPk and mPw are adequate to differentiate between maritime polar outbreaks having longer trajectories. (See fig. 7.) The unusual instability of mAk air, some flights indicating that vertical convection has obtained to at least 6 km., has two important effects on its interaction with other air masses in the central and eastern part of the United States. First, since often it is colder aloft than the surrounding air masses, sinking from these levels, or subsidence, occurs in mA and mP air. Second, and inversely, this same instability in mA air is apt to cause an increasing tendency for vertical divergence and increasing instability in air masses moving into a region occupied or recently occupied by mA

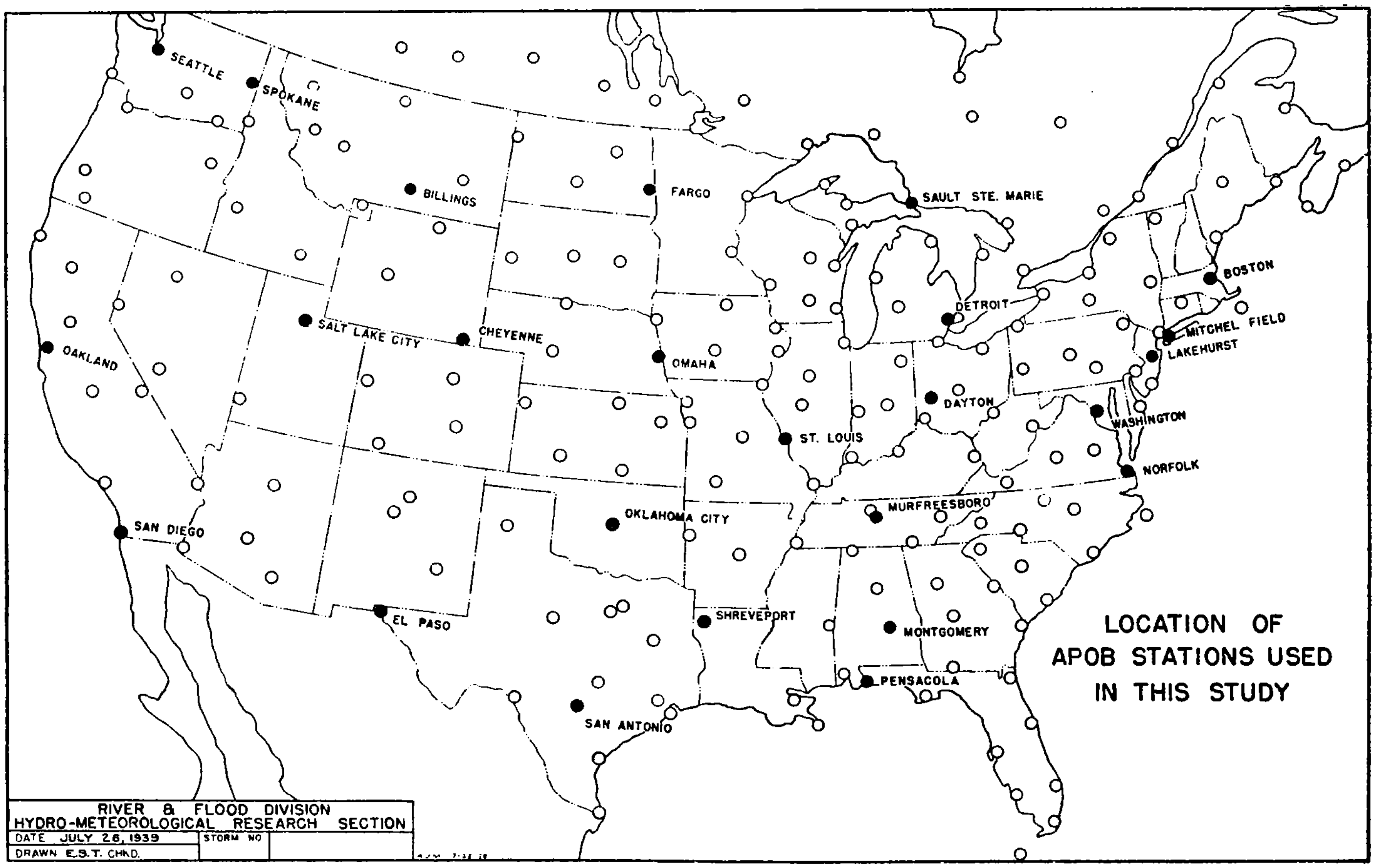


FIGURE 1.

very nearly tropical properties it is evident that the observed amount of moisture could not have been carried up to that elevation by simple vertical convection. The addition of moisture at higher levels in modified polar air is probably best explained by the theory of horizontal mixing along isentropic surfaces as discussed by Rossby (*6*).

Maritime Arctic air, mA

When an outbreak of polar air moves over only a very small part of the Pacific Ocean before reaching the United States it is usually designated as mAk. If its trajectory has been far to the south, it usually is sufficiently modified to be called mP. Since mA air must have properties closely resembling those of cA air before moving out over the ocean it is possible to estimate the minimum values of its various properties. Assuming a pressure of 1,000 mb. at the surface, which is a reasonable value for a winter mA current, a minimum temperature at the surface of 0° C. and 75 percent of saturation as would be expected in this air. In other words, the mA gains in stability while the surrounding masses lose.

During the winter months mA air near the surface is usually warmer than the continent, and shortly after passing the coast line it becomes a warm type air mass according to the Bergeron classification. Over snow covered areas mAk air very rapidly assumes continental characteristics; thus we find the modified form of mA air sometimes colder near the surface than the original.

Because of the mountain ranges in the western part of the United States and the presence at the surface of cold continental air, most of the Pacific air masses in winter move eastward over the continent without reaching the surface, except in certain unusually warm winters.

The effects of surface modification on polar Pacific air masses over the United States are but slight in the winter months except as the air masses approach the more southerly stations. The mean values for mP air cannot be

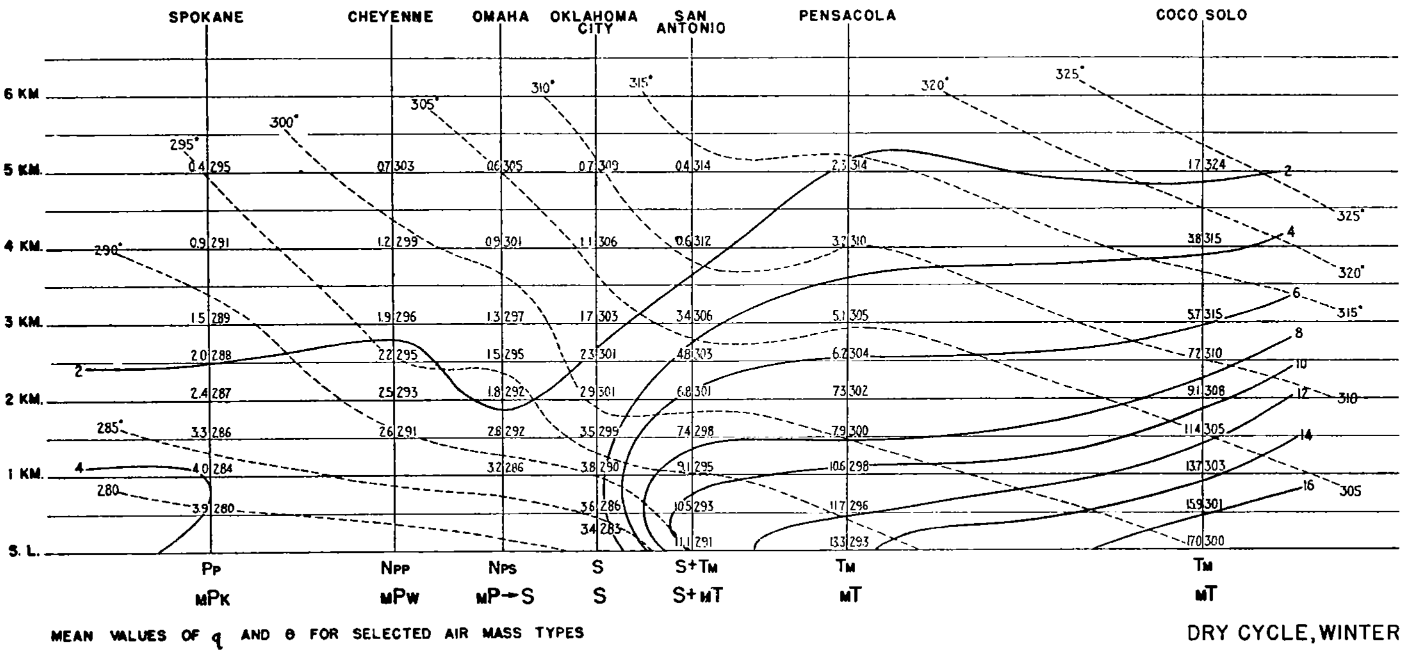


FIGURE 2.

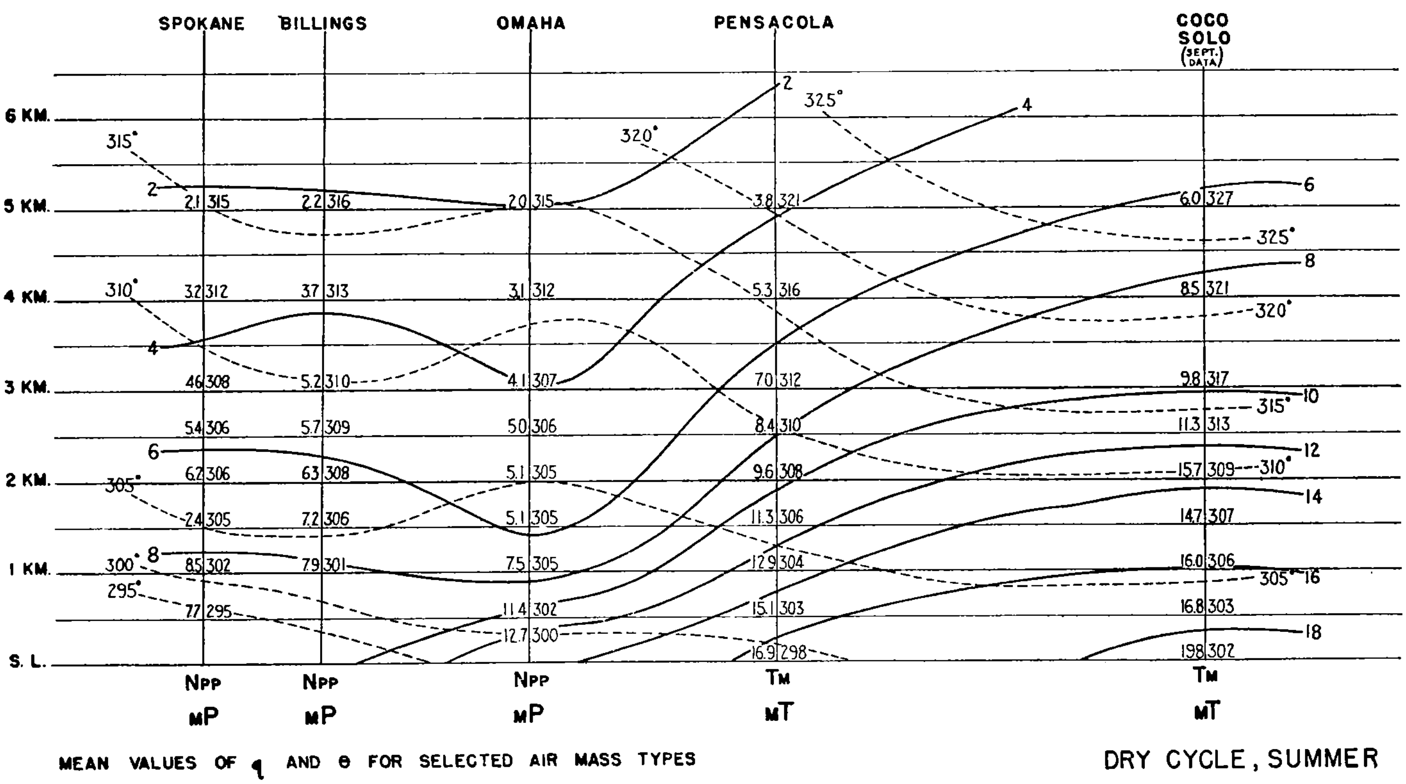


FIGURE 3.

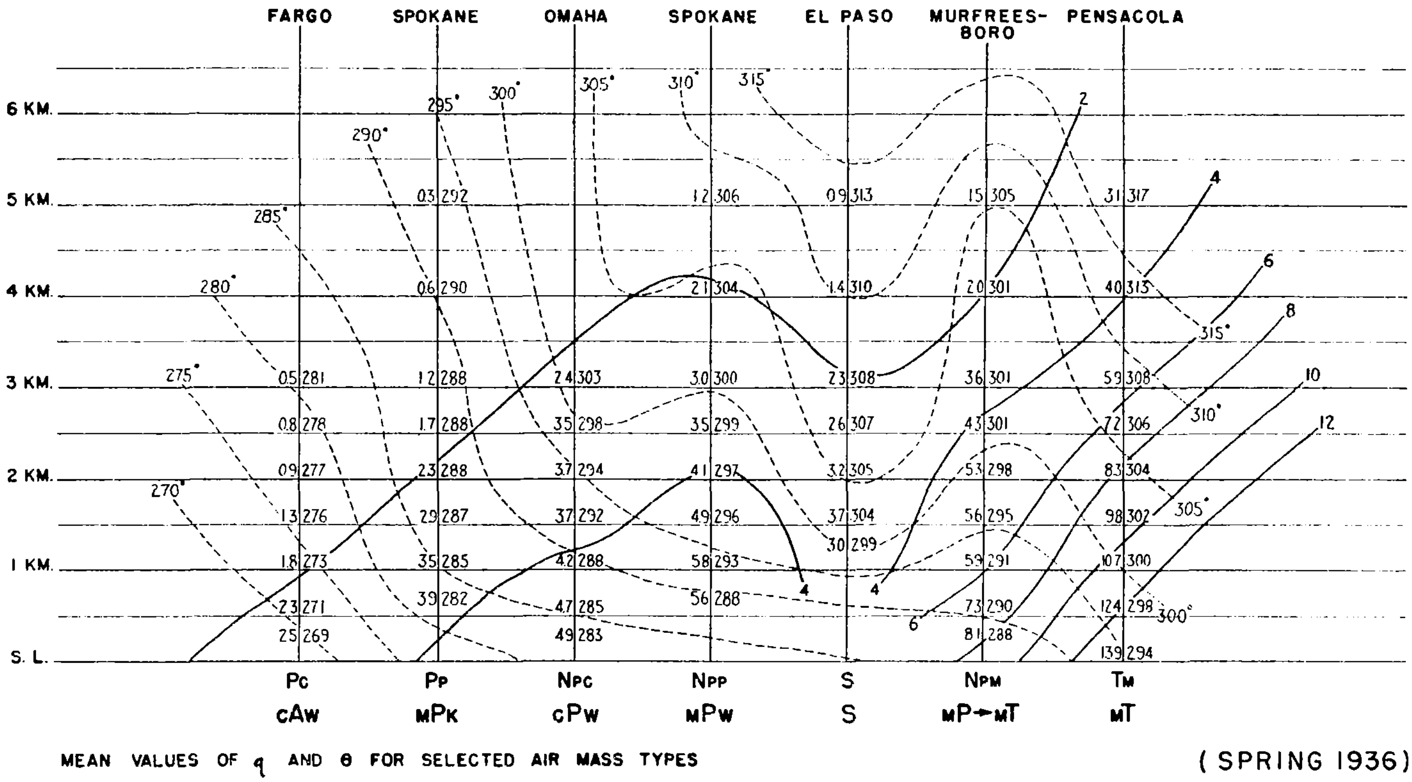


FIGURE 4.

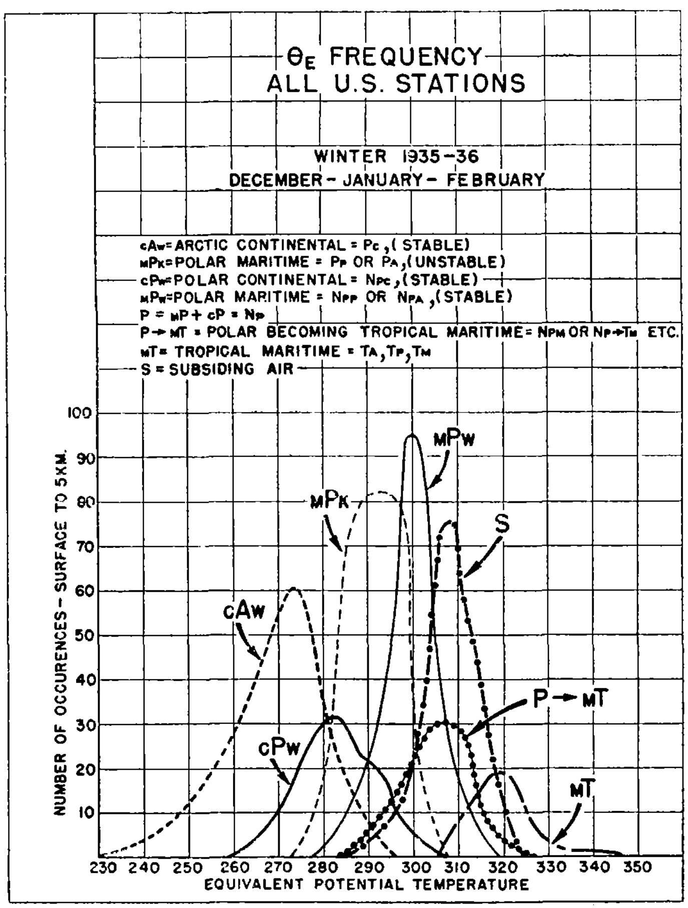


FIGURE 5.

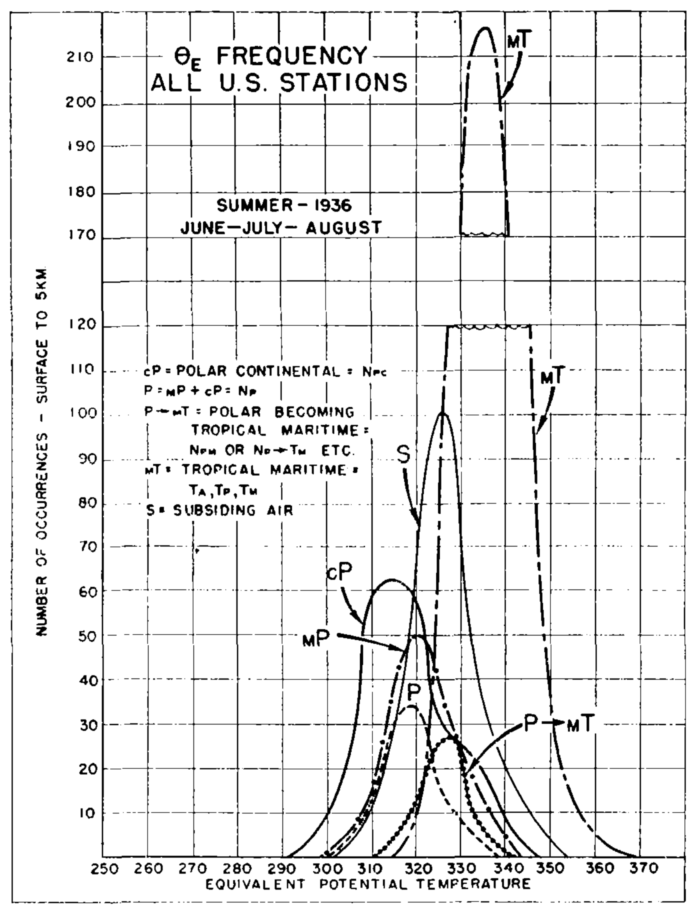


FIGURE 6.

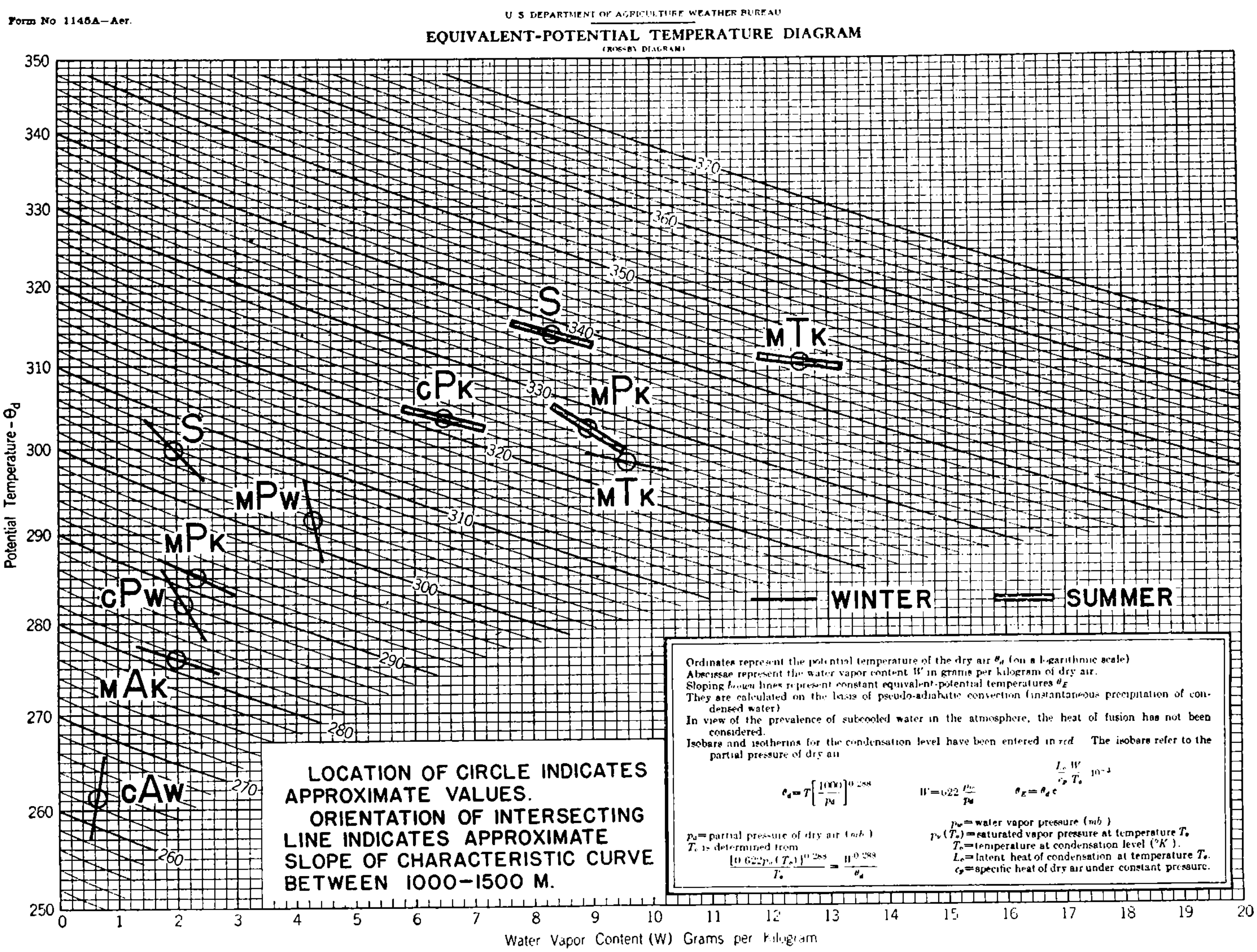
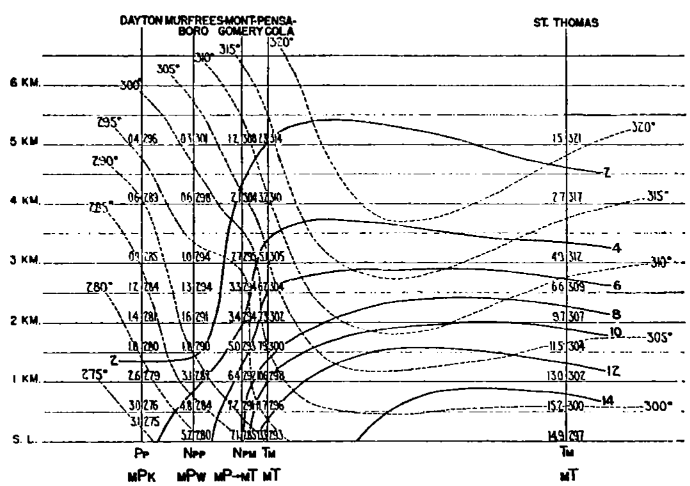


FIGURE 7.

considered representative of the effects of continental modification; first, because the notation mP is also applied to air masses which have had a trajectory far to the south over the Pacific Ocean; second, because of the tendency for subsidence in Polar Pacific air, a large number of samples of the modified form of this air mass have been classified as S air in the course of this study; third, because a few samples of modified Pacific air which were rapidly assuming tropical maritime characteristics were summarized under a special group. It seems safe to say that some of the increase in moisture at higher levels cannot be explained by vertical transport and must be explained by isentropic mixing.

Samplings of maritime polar air from the Atlantic, and its modified forms are quite rare in the winter months because this type of air mass is usually off the New England coast, and when it does move inland its tendency for instability and saturation usually results in conditions too hazardous for flying. The few samplings available in this and other studies indicate that Polar Atlantic air in



MEAN VALUES OF q AND θ FOR SELECTED AIR MASS TYPES   MOIST CYCLE, WINTER

FIGURE 8.

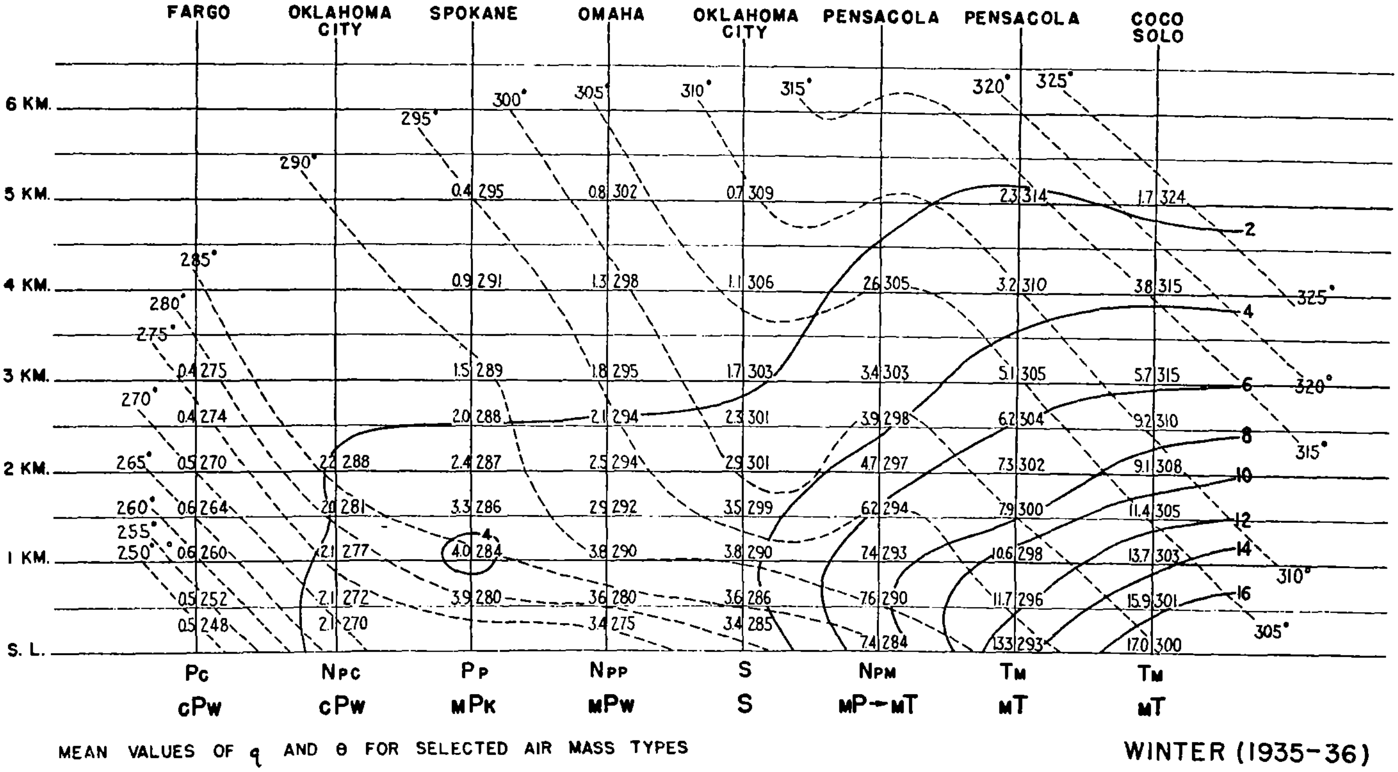


FIGURE 9.

general develops the same distinguishing properties as Polar Pacific but vertical convection has not reached to such great heights.

Maritime tropical air mT (Tm)

It is unfortunate that only a few soundings in mTw air were made during the winter selected for this study; but since the source region for mT air exhibits only minor variations from one year to the next, even a few samplings of mTw air can be considered representative of its general characteristics. Since mT air is formed out of air which was originally polar, it shows a tendency for vertical stability with some subsiding action in the higher levels. It will be noted that although the partial-potential temperature of the dry air increases fairly rapidly with elevation, the equivalent-potential temperature usually decreases with elevation. This seems to indicate that at higher levels this air mass is relatively dry. Since mT air usually moves inland with anticyclonic motion it may be assumed that the relative dryness aloft in mT air can be explained by horizontal divergence with subsidence in the upper levels of the subtropical anticyclonic cell. There is evidence that some of the water vapor at higher levels must have been carried upward by vertical convection over scattered areas in the Gulf and Caribbean, and was diffused to the surroundings. The evident upward slope of the isentropic surfaces to the northward indicates that the moisture is carried aloft not only by vertical convection but also by isentropic mixing. The upward transport of moist air appears to occur near the edges of the subtropical anticyclones, while the subsiding dry tongues originate nearer to the centers.

Due to the lack of adequate history for the trajectories of tropical maritime air entering the western part of the United States, it is difficult in most cases to identify positively Tp air masses as such. From a comparison of average surface temperatures over the Pacific Ocean and the Gulf and Caribbean area (**7, 8**), it seems that an air mass would have to move about 5° of latitude farther to the south to attain comparable amounts of heat and moisture over the Pacific. The persistence of the anticyclone off the California coast with very dry air aloft

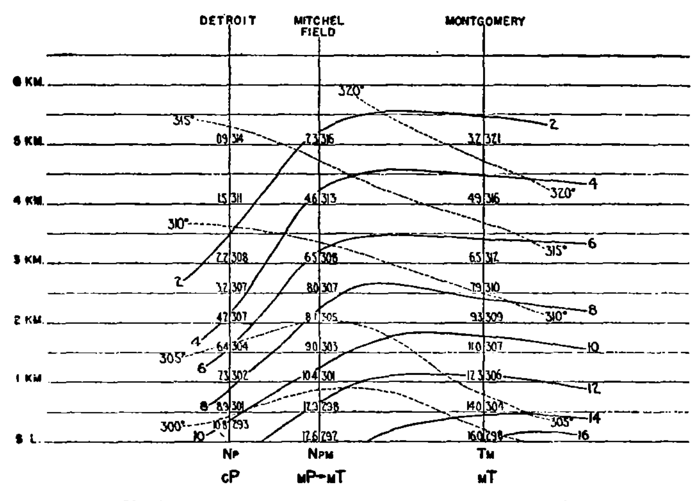


FIGURE 10.

seems to demand that in any northward movement, tropical Pacific air would be exposed to likelihood of both horizontal isentropic mixing and mechanical vertical mixing with much drier air. Not enough samplings of Tp air are available to show definitely that it possesses any characteristics distinct from tropical Atlantic air. The values obtained for Manila by Deppermann (**9**) seem to agree well with the values obtained for Coco Solo and St. Thomas in this study.

Superior or subsiding air S (Ts)

The notation Ts (tropical superior) was originally applied to air supposed to have been derived from the upper subsiding portions of the subtropical anticyclonic cells (**2**). However, of recent date the designation S has been applied to all warm air masses that show relative humidities below 40 percent, which is taken as an indication of subsidence and horizontal divergence. The study indicates that most of the dryness results from the subsidence of high level air from a polar source. Isentropic analyses have shown definitely that a number of dry tongues move out from polar regions. Consider for example the potential temperature surface of 302° A.; mP air shows an average specific humidity of 0.8 g./kg. for that surface, and mT air an average of 7.3 grams. The average value of 2.0 g./kg. given for S air at this surface indicates that the main source of the dryness in S air is probably the upper levels of the polar air, but that the average also includes a number of cases of air of tropical or subtropical origin as well as cases of isentropic mixing between air from tropical regions and subsiding air of a polar source. Further studies of the general circulation on the basis of isentropic charts may show that all dry air aloft, even in the tropics, comes from high latitudes.

Modified moist Polar air mPw (NPM)

All of the various types of modified polar air which were rapidly becoming warm and moist were grouped under the heading of NPM for purposes of this study. The mean values for these air masses show a tendency for decreasing stability and increasing moisture content. Although there is evidence that considerable heat and moisture are added by surface effects, there must be an addition of moisture aloft by isentropic mixing. The fact that a large number of NPM soundings show humidities at or near saturation makes it impossible to make quantitative estimates of the effects of addition of moisture at the surface. In other words, conditionally stable air under saturation conditions moves along equivalent-potential temperature surfaces, and prior to saturation the air moves along potential temperature surfaces (**10, 6**), and since the mean values represent a large number of saturated conditions it is impossible to differentiate between the effects of vertical convection and isentropic mixing in NPM air.

SUMMER SEASON

Continental polar air cA→cP (Pc→NPC)

As explained by Willett (**1**) surface conditions in the source region of cA air in the summer are considerably different from winter conditions. Both the mP and cP are originally Arctic air masses and have similar properties at their source, but undergo different influences on their journey to the United States. cA→cP air undergoes very rapid surface heating and slow addition of moisture. Since so few cases of cA air have been classified as such it is safe to say that during the summer months all outbreaks of cold continental air are sufficiently modified to be labeled cP by the time they reach the United States. Because most of the flights are taken before sunrise the mean values for cP air show great stability up to 2 km. As noted by Willett (*1*) there is a large diurnal range in the temperature in continental air during the summer months so that by midafternoon on clear days most of the stability in the lower 2 km. has been removed. The rate of increase of moisture aloft seems slightly in excess of that possible through vertical convection and it is necessary to believe that horizontal mixing plays an important role.

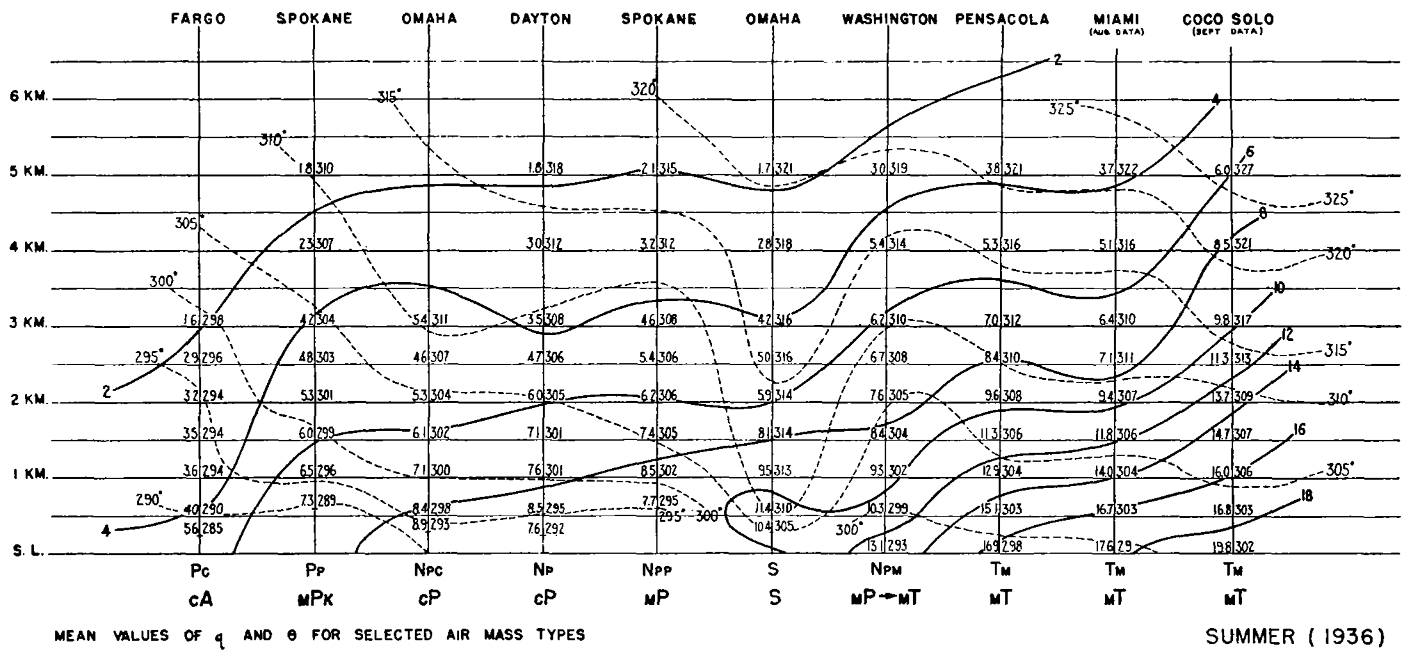


FIGURE 11.

Maritime polar air mA→mP (Pp→Npp)

The source of mA air is originally Arctic, but its trajectory over the Pacific Ocean leads to a fairly rapid increase in moisture. However, because of the cool waters of the Pacific and the small diurnal range in temperature over the water, the addition of heat is slower than it would be over the land. As soon as the maritime air mass moves inland it is heated very rapidly. Further, because of the usually long maritime trajectory, polar Pacific air masses are quite warm as a rule by the time they reach Spokane or Billings, so it is usually advisable to use the notation mP during the summer months.

Although it is not so pronounced in the summer time, the tendency for subsidence in Pacific air masses moving across the Rockies has about the same general effect as it has during the winter months. There is a rather large diurnal temperature range in mP air over the land and apparently considerable moisture is added by vertical convection in the lower levels.

The effects of subsidence and outflow from the upper portions of mP air seem to have about the same prominence as the effects of horizontal mixing so the mean values for mP air do not give positive evidence of the increase of moisture aloft by isentropic mixing.

The notation cP or Np should be used in cases of doubtful history of the polar current, or in cases of overlapping layers of maritime and continental air having been thoroughly mixed by vertical convection during the day or in some cases by mechanical turbulence. Since there is so little difference in the properties of mP and cP after 1 day's history over the continent during the summer months it would be wise to label all polar air masses cP in the summer time, after they have moved east of Spokane and south of the Candian border.

Modified moist polar air mP (Npm)

This group, as in winter, includes all polar masses which are rapidly assuming tropical maritime characteristics. The rapidly increasing moisture seems to be a combination of the effects of surface evaporation over water surfaces or areas with abundant plant life, coupled with the effects of horizontal mixing. It seems possible therefore for a polar air mass with a purely continental history to attain in summer quantities of heat and moisture comparable to those obtained by an air mass moving over the Caribbean Sea.

Maritime tropical air mT (Tm)

The source region and characteristics of tropical Atlantic air are about the same in summer as in winter. The effect of continental modification is reversed in summer, however, and the air mass is heated rapidly at the surface as it moves inland and mT air masses very frequently become unstable during the day. It appears that in general the potential temperatures are higher in mT air than in continental air masses and that therefore the air would move upward along the isentropic surfaces as it came over the land. Some of the cases studied indicate that at times a given isentropic surface may slope downward from the Gulf to the continent. This means that portions of the mT column may at times move downward in approaching the continent. It will be noted that mean potential-temperature surfaces are approximately horizontal between Miami and Pensacola.

Taking the vertical distance in meters between the 303°A. and the 311°A. surfaces as an inverse measure of stability, one finds the mT air to be more stable in the mean than mPk air but less stable than cPw air. This agrees with the statement made during the discussion of mP air wherein the author stated that mP air was likely to cause increasing instability in air masses moving into its territory. The author is of the opinion that it can be statistically proved that the greatest probability of rain occurs when mT air replaces mA or mP, or when mA or mP replace mT air. The latter sequence is more conducive to precipitation during the colder seasons.

Samplings of tropical Pacific air were not included for the summer season since such an air mass is extremely rare over the United States during that season and has no properties different from other maritime tropical air masses.

Superior or subsiding air (S)

The assumption that the dryness of this air mass is due to subsidence is not necessarily correct in summer, because rapid surface heating of relatively dry air at that season may produce a deep column of air whose moisture content is far from the saturation values. When such an air mass is cooled during the night by surface radiation some slow sinking may occur in the layers near the surface and those layers which are not cooled by radiation will show low relative humidities by the time of the airplane observation the next day. Since S air is recognized only on the basis of relative humidities less than 40 percent, the source of this air can therefore be traced to subsiding polar or tropical air or to rapid daytime heating of either type.

The range in specific humidity and equivalent potential temperature is considerable at all elevations for the dry type of air called S, so it can be assumed from this evidence also that the source of S air can be either polar or tropical or a stratification of air from both sources with a tendency for horizontal mixing along the isentropic during the night and vertical convection during the day resulting in a dissipation of the concentration of moisture. The orographic effect also plays an important role in the development of S air east of the Rocky Mountains.

AIR MASS CLASSIFICATION

The above discussion has treated mainly the important identifying characteristics of each type of air mass for the winter and for the summer months based in general on Willett's classification. Data have also been computed for the spring and fall seasons and are published here, figures 13 and 15. The study indicates that it is possible to make some reasonable standardization of air mass classification for synoptic purposes but that any classification falls far short of definitely identifying the thermodynamic properties of the different air masses. In other words the mean values of each of the various properties (see figs. 12 to 15) show definite groupings for the different air masses, and the individual values show definite limits for the properties of fresh tropical and fresh polar outbreaks. However, the modifying influences affecting air masses and the almost arbitrary method of classifying air masses, especially in the summer months, result in a very wide range of equivalent-potential temperatures as indicated on the frequency distribution charts (figs. 5 and 6). It can be seen from a study of these charts that the classification is relative for any one day, and no definite limits of equivalent-potential temperature have been in use. This seems regrettable for statistical purposes but in practical synoptic work it can hardly be avoided.

It is usually the practice to label the air masses differently on either side of a front, and since polar air is sometimes modified very rapidly, it happens that modified polar air behind a cold front on one weather map may have a higher equivalent-potential temperature than a modified tropical current behind a warm front on a map a week later. Since all tropical air is polar air modified by surface effects, any classification of air masses must be only a compromise as to number of types. The author is of the opinion that no purpose is served by increasing the

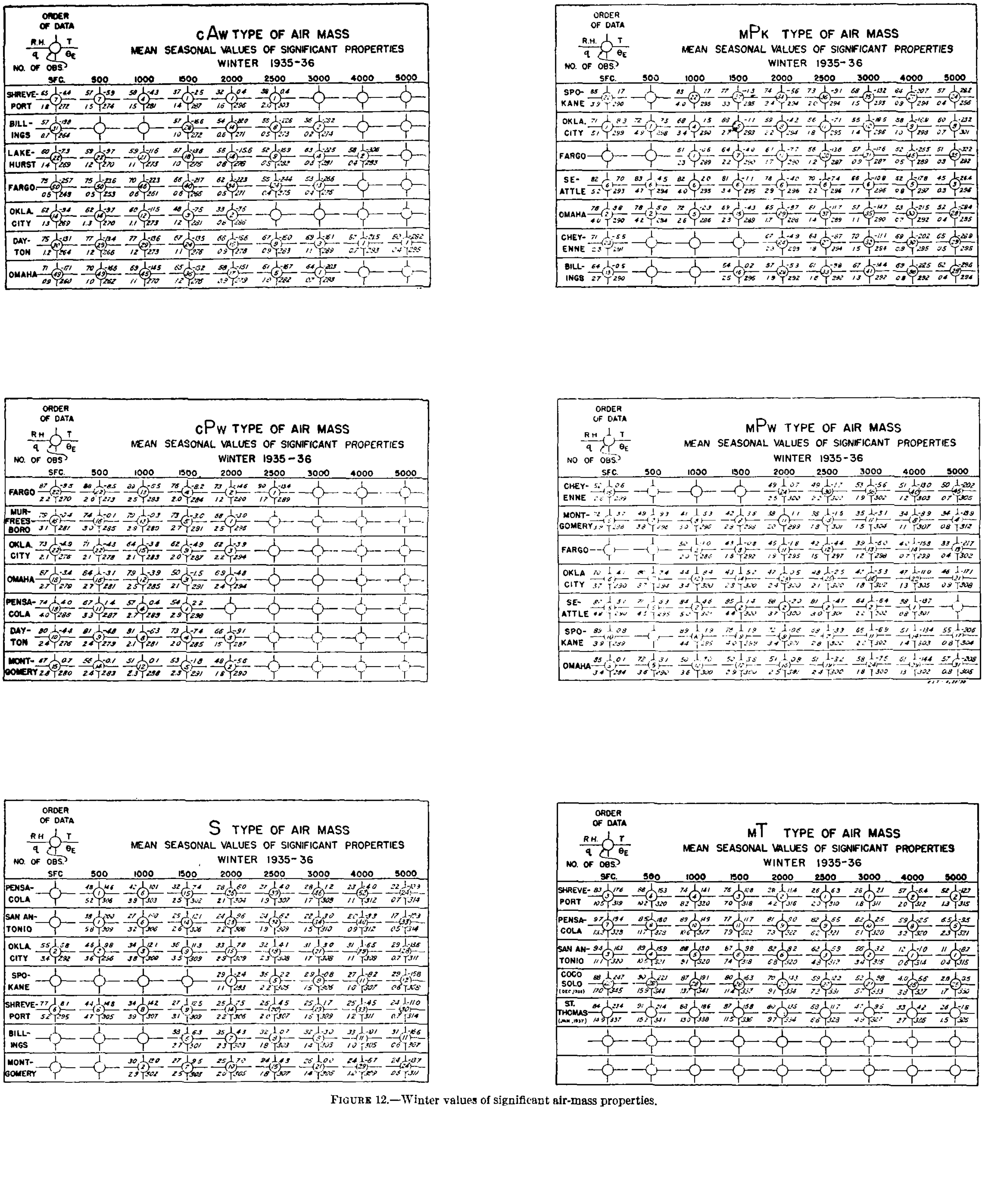


FIGURE 12.—Winter values of significant air-mass properties.

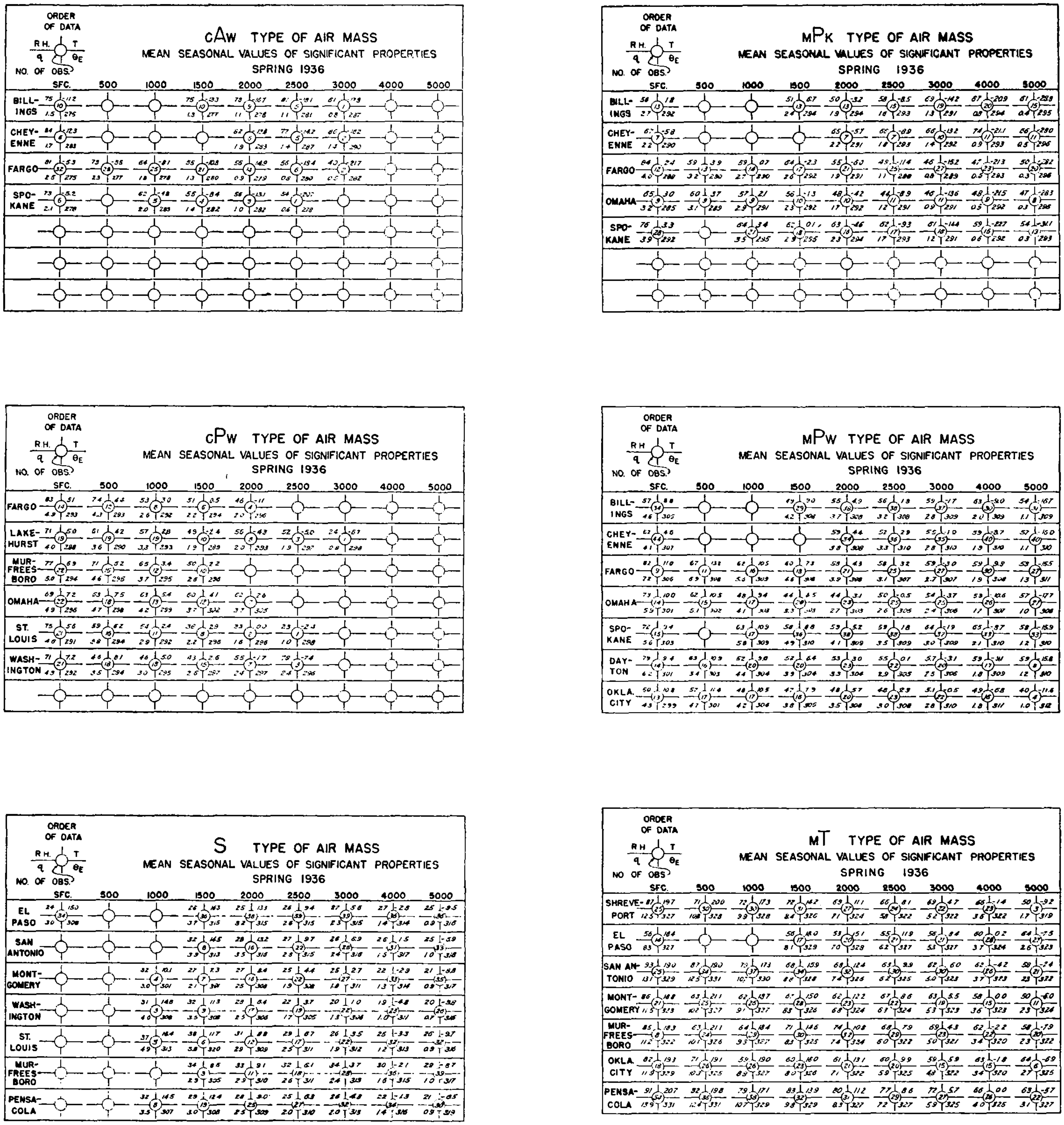
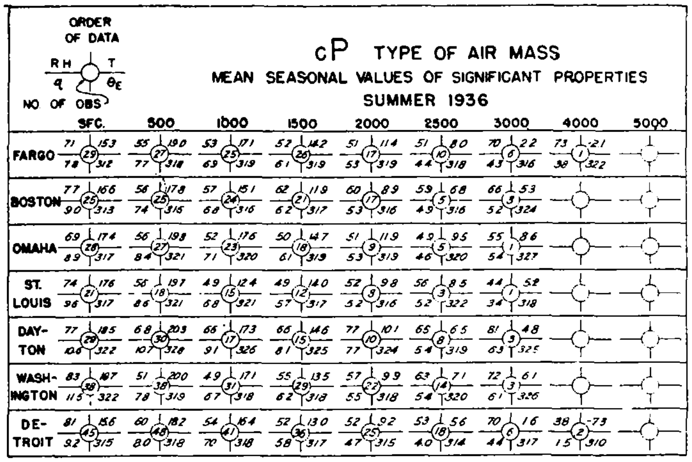
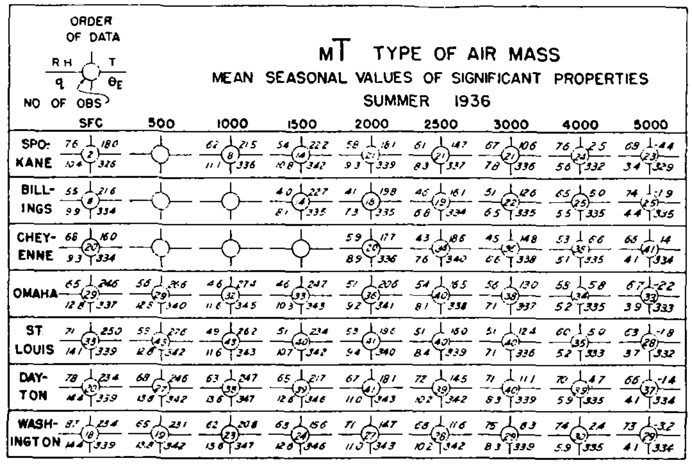
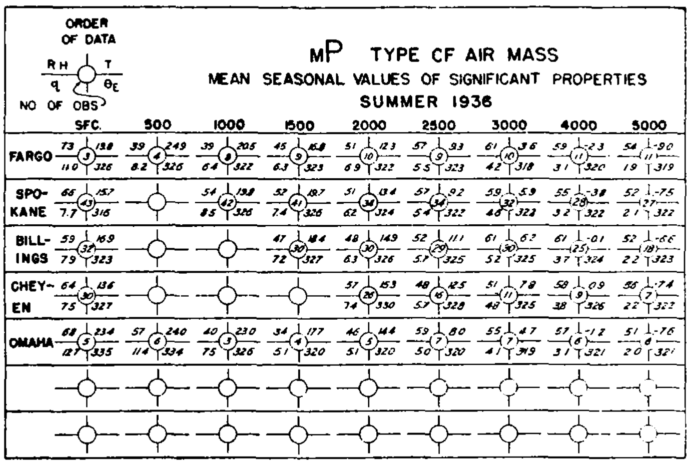
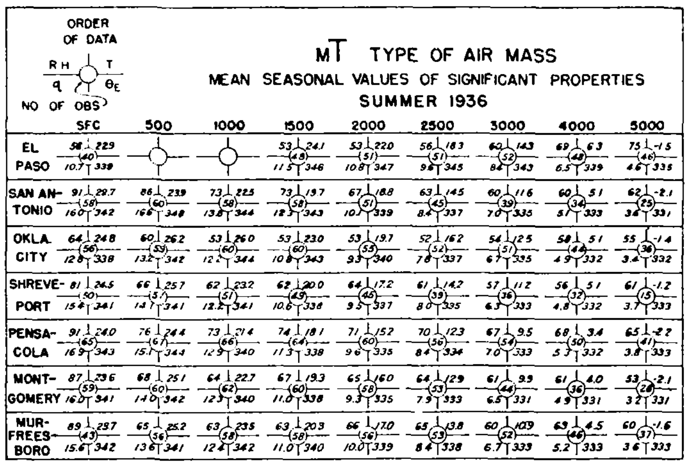


FIGURE 13.—Spring values of significant air-mass properties.









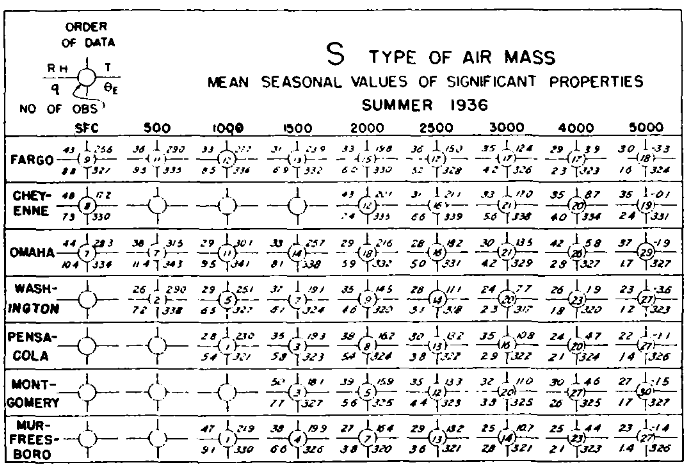


FIGURE 14.—Summer values of significant air-mass properties.

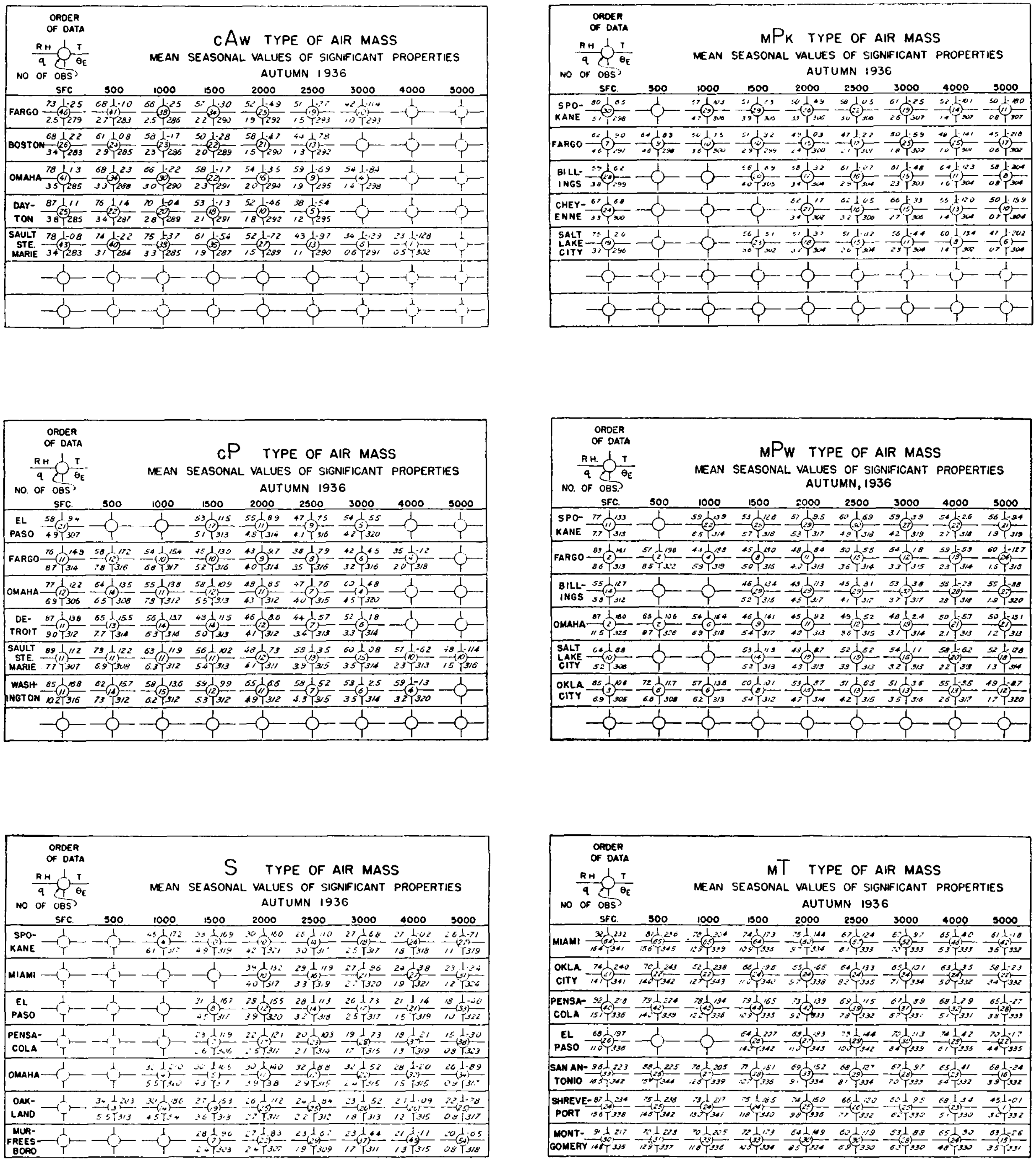


FIGURE 15.—Autumn values of significant air-mass properties.

number of types. The three main air masses, cA, mA, and mT have definite distinguishable properties; but the modified and mixed forms of these air masses may assume an entirely different set of characteristics. Further, since the relative dryness of an air mass is sometimes considered in its classification, the effects of pressure distribution alone may cause a change in label for the air mass.

The use of equivalent-potential temperature identifies the amount of heat and moisture in an air mass, and the relative humidity gives an indication of the degree of saturation. It has been suggested that a classification system be adopted using only the above two properties as arguments. The major objections to such a system are that the number of possible combinations becomes too large, it has no geographical significance, and it gives no indication of vertical stability. Therefore it seems advisable to continue the use of the three major types Pc, Pp, and Tm, since they immediately convey indications of heat and moisture content and of vertical stability. In the wintertime the notations Npa, Npp, and Ntm also appear satisfactory. Tp is rare in occurrence in the United States, especially in the summer, and its properties must be very similar to Ta air, so it seems advisable to use only the symbol Tm for all tropical maritime air masses. Pa is also rare at coastal stations but it often goes all the way around a Hudson Bay cyclone and enters the United States from the north. The characteristic properties of Pa and Pp should not be appreciably different, so only the symbol Pm should be used in such cases since there is often a current of Pp air flowing parallel to the Pa current. Whenever there is reason to believe that Pc and any polar maritime air mass have been mixed by mechanical turbulence or by convection, the notation Pc should be used since most of the maritime characteristics have probably disappeared.

In midsummer all polar air masses are so rapidly modified over the continent that it seems advisable to use only the symbol Np for all polar air masses over the continental United States at that season. At all seasons when a polar air mass is rapidly assuming tropical maritime characteristics it is suggested that it be called Npm. A study of samplings of Npp→Tp, Npp→Tm, Np→Ta, Np→Tm, Pa→Npa, Npc→Ta, and Np→Ta shows no definite distinguishable properties and all of these air masses can be called Npm and still have as much practical synoptic significance.

It seems necessary to continue the use of the symbol S to describe dry subsiding air masses. As soon as the air mass shows signs of being lifted the symbol S should be dropped since it would then be very misleading. The use of the notation Nps is suggested for polar air masses apparently in the early stages of subsidence.

In summary, the use of the following air mass types is considered of practical synoptic significance for the United States: For most of the year: Pc, Pa, Pp, Pm, Npc, Npp, Npm, Nps, Tm, and S. For midsummer: Np, Npm, Nps, Tm, and S. However, since the above labels do not identify the stability of the lower levels of the air mass, it has been recommended that the differential classification of Bergeron be adopted as explained in an earlier paragraph.

THE AIR MASS CYCLE

Following the above-suggested classification it is possible to identify two distinct cycles of transition from polar to tropical air, one a moist cycle with rapid addition of moisture, the other a dry cycle with a marked subsidence and slow isentropic mixing in the early stages. An attempt to identify these cycles for the winter and summer seasons has been made on figures 8 to 11.

For the winter season the moist transitional stage, figure 8, from mP as represented at Dayton, to Tm at Pensacola and St. Thomas, shows continual subsidence and increasing moisture. The persistent stability throughout the transitional process, the difference in potential temperature between 500 m. and 5,000 m. remaining practically constant from the mA to the Tm stage, indicates that the principal addition of moisture must occur by means of mixing along isentropic surfaces, with some probability of convection in the final mT stage.

The dry winter cycle, figure 9, shows rapid subsidence with slight increase of moisture by isentropic mixing from the mA to the S stage. When this air mass moves to lower latitudes the subsidence decreases, rapid surface heating develops and the S air begins to mix both vertically and horizontally with mT air. The vertical mixing is probably confined to the lowest layers affected by daytime convection and most of the increase in moisture aloft appears to be due to isentropic mixing.

The identification of the moist and dry cycles is more difficult in the summer season because of the greater tendency for vertical convection during the day, with convection occurring under saturated conditions which cannot be analyzed by charts using potential temperature surfaces. However, the mean values, indicating unsaturated conditions, suggest for the moist cycle conditions similar to those observed in the winter season, namely, subsidence and surface heating with rapid increase of moisture by isentropic mixing.

The dry cycle for summer is more difficult to identify because the driest stage, S at Omaha, as shown in individual cases, is not clearly shown by the mean values for S at that station. In other words, some of the flights used in computing means for S air at Omaha may reprseent returning subsiding tropical maritime currents.

Examination of the mean isentropic chart for mT air in summer shows the tongue of air with highest moisture content to be probably subsiding as it moves northeastward from El Paso to Omaha. The apparent upward slope of the isentropic surfaces from Omaha to Pensacola is partly due to convergence and daytime convection over the Gulf coastal regions. The mT air at El Paso represents a more advanced stage of development than mT at Pensacola. The flow pattern suggested by the mean isentropic chart for summer mT indicates that the immediate trajectory of the mT air at El Paso is from the lower Caribbean area. The study indicates that appreciable quantities of heat and moisture may be added to mT air over the continental United States. The highest value of equivalent potential temperature, 366° A., observed during this study was found at 1,000 m. at Dayton on August 22, 1936.

The dry cycle in summer then represents rapid modification of the polar air masses with subsidence aloft and slow addition of moisture by isentropic mixing over the continent, then continued heating accompanied by vertical convection and convergence over the Gulf and Caribbean, followed by a slow spreading out and subsidence as the air assumes an anticyclonic trajectory on its return from the lower Caribbean to El Paso. From El Paso to the Mississippi Valley there is apparently a continued addition of heat and moisture and the mT air again becomes convectively unstable over the Mississippi and Ohio Valleys.

In the identification of air masses aloft in practical synoptic work it is recommended that attention be paid to the mean seasonal values for each of the principal air

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mass types and also to the probable range of equivalent-potential temperatures. In view of recent discoveries of the meteorological significance of isentropic charts it is further recommended that more attention be given to the slope of potential temperature surfaces in situations free from condensation. Allowance should be made for the possibility of horizontal mixing on isentropic surfaces and unless the isentropic surfaces in one air mass actually intersect the ground or at least show a sudden increase in slope, the synoptic analyst should label the air masses differently with caution.

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NOTES AND REVIEWS

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This book, as implied by the title, emphasizes the physical rather than the descriptive or statistical aspects of meteorology; it is primarily an elementary exposition of the fundamental physical laws to which atmospheric phenomena conform, and an application of these laws to the explanation of the more important physical phenomena of the atmosphere. The book is intended as an introductory college textbook. It presupposes a working knowledge of physics, although a chapter on the principles of the theory of heat is included. The treatment is essentially nonmathematical, but a number of simple mathematical formulae are quoted and derivations are given for most of them.

The introductory chapter is devoted to a description of the scope of meteorology and its place among the sciences, with a brief historical sketch. After a chapter on the atmosphere in general, the succeeding chapters consider in detail, barometric pressure, temperature, insolation, and atmospheric water vapor. A chapter on the thermodynamics of the atmosphere includes a discussion of lapse rates and stability; and is followed by chapters on the wind, the dynamic theory of air movements, and a brief description of the planetary circulation. Consideration is next given to condensation, clouds, and the various forms of precipitation, followed by two chapters on tropical and extratropical cyclones, including a description of tornadoes and brief reference to the methods of air-mass analysis. The book is concluded by chapters on atmospheric electricity (including the aurora), thunderstorms and lightning, atmospheric acoustics, and atmospheric optics.—*Edgar W. Woolard.*

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[Richmond T. Zoch, *in Charge of Library*]

By Amy P. Lesher

RECENT ADDITIONS

The following have been selected from among the titles of books recently received as representing those most likely to be useful to Weather Bureau officials in their meteorological work and studies:

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